Estimation of 1D Proximity Budget Impacts due to Light Source for Advanced Node Design

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ABSTRACT

The laser impacts on the proximity error are well known in many previous studies and papers. The proximity budget control is more and more important for advanced node design. The goal of this paper is to describe the laser spectral bandwidth and wavelength stability contributions to the proximity budget by considering general line/space and trench pattern design. We performed experiments and modeled the photolithography response using Panoramic Technology HyperLith simulation over a range of laser bandwidth and wavelength stability conditions to quantify the long term and short term stability contributions on wafer-to-wafer and field-to-field proximity variation. Finally, we determine the requirements for current system performance to meet patterning requirements and minimize the laser contribution on proximity error and within 4% of target CD Critical Dimension Uniformity (CDU) budget process requirement [2]. This paper also discusses how the wafer lithography drivers are enabled by ArFi light source technologies.

Keywords: Proximity budget control, laser spectrum, photolithography simulation

1. INTRODUCTION

Advanced node designs require tighter process control, and especially the Critical Dimension Uniformity (CDU) error need to be controlled within 4% of target CD [2]. In order to achieve this, we have to more acutely maintain tight Iso-Dense Bias (IDB) control as part of the overall Optical Proximity Effect (OPE) portion of the Critical Dimension (CD) Budget. The laser bandwidth E95 is the one of the OPE contributors that need to be considered.

By studying through-pitch performance of line/space and trench pattern design which effect by laser bandwidth E95, we first performed lithography simulations to understand the CD error effect by bandwidth E95, and then verified the results by wafer exposure experiments. This enabled determining the CD error sensitivity as a function of changes to bandwidth E95.To determine the proximity budget contribution by laser performance variations, the wafer-to-wafer and field-to-filed performance during wafer exposures was analyzed for multiple systems using SmartPulse data collection. Based on the sensitivity of proximity variation, we could then quantify the laser population contributions to CD error variation for the current advanced design node. We also determined laser bandwidth E95 stability needed in order to meet the control requirements for the next generation advanced design node.

2. SIMULATION

2.1 Simulation conditions

Figure 1. illustrates the binary mask Line/Space and Trench feature through pitch for the simple 1D design with pattern duty cycle up to 10 were simulated. For the semi-ISO and ISO pitch feature, sub-resolution assistant features (SRAFs) were used, and also mask biases were applied to compensate optical proximity effects. Figure 2. shows the two types of illumination conditions (193nm immersion + strong OAI illumination + Polarization) with Hyper-NA 1.35. In order to estimate the CD error response to bandwidth E95 changes, we used the Modified Lorentzian spectral approximations to generate the spectral profile as Figure 3. for Panoramic HyperLith simulation.

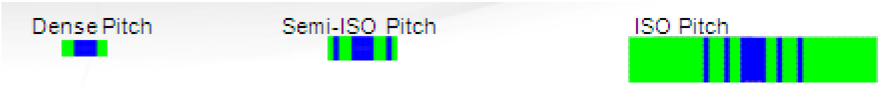
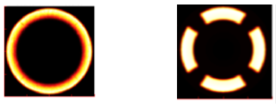
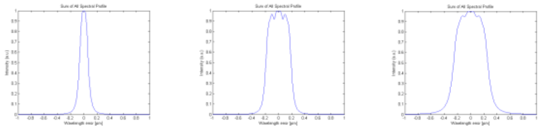


Figure 1. Feature from dense pitch to ISO with SRAF



For Line/Space For Trench

Figure 2. Illumination Settings



E95=300fm E95=450fm E95=600fm

Figure 3. Simulated Laser Spectral Profile for Various Bandwidth E95

2.2 Simulation results

The figure 4.(a) and (b) shows the simulated CD error response to E95 bandwidth changes. An increase in E95 bandwidth leads to an increase in focus blur effect (or contrast loss) on the wafer. The pitch-A (Line/Space) or pitch-A' (Trench) is dense pitch; the pitch-I (Line/Space) and pitch-V' (Trench) are ISO pitches, therefore having larges impact on changes in CD. In general when bandwidth increases, the CD decreases most for the semi-ISO (forbidden pitch) and ISO pitch, which are structures also most sensitive to the contrast changes. All the pitches are referenced to the bandwidth E95 of 300fm, since this is the nominal set-point for XLR 660ix bandwidth control. We calculated the relative the CD error from the 300fm bandwidth E95 reference. From simulation result show, the pitch-C (Line/Space) and pitch-I' (Trench) are the most sensitive pitches to contrast or bandwidth E95 for these patterning conditions. For each pitch we normalized the CD error to the target CD for that pitch at the baseline bandwidth E95 of 300fm.

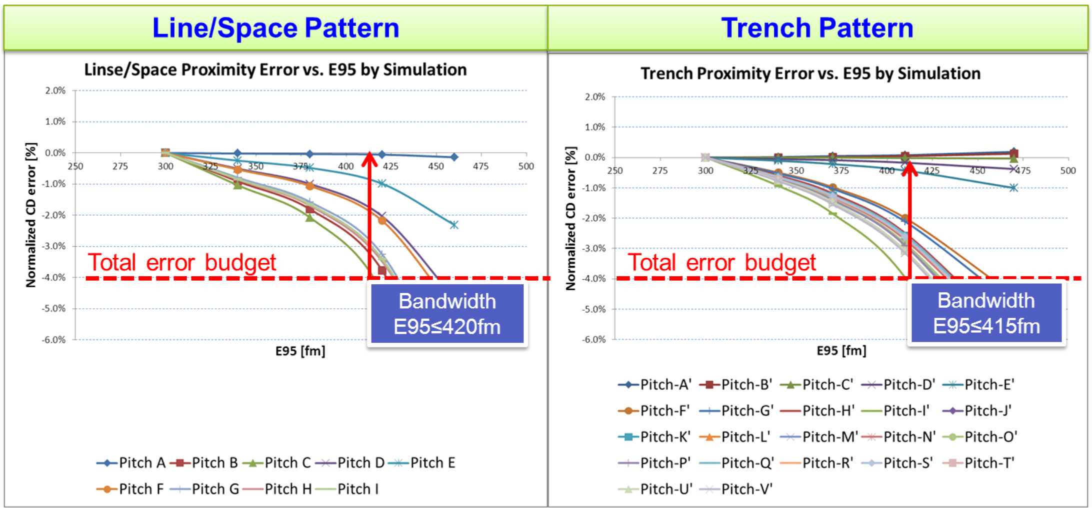


Figure 4. (a) Line/Space Simulation Result Figure 4. (b) Trench Simulation Result

3. WAFER EXPERIMENT AND DISCUSSIONS

3.1 Wafer experiment conditions

Wafer exposure experiments were carried out to test Trench pattern response to changes in laser optical parameters, in order to determine the on-wafer bandwidth E95 response. As shown in Figure 5, we tested three E95 conditions with nominal E95 (292fm), setting-1(E95 = 385fm) and setting-2 (E95 = 475fm) on the XLR660 ix system. The actual laser performance during wafer exposure was obtained by using SmartPulse data collection, which enables collection of per wafer laser beam and optical parameters during wafer exposure, as described in Figure 6. We measured the on-wafer CD through pitch by CDSEM, and obtained the exposure bandwidth E95 values for the actual wafers exposed to determine the direct correlation. The bandwidth E95 data reported in Figure 5, in this controlled experiment, are an average of all fields per wafer.

	Nominal	Setting 1	Setting 2
E95 [fm]	292	385	475

Figure 5. Bandwidth E95 Experiment Conditions

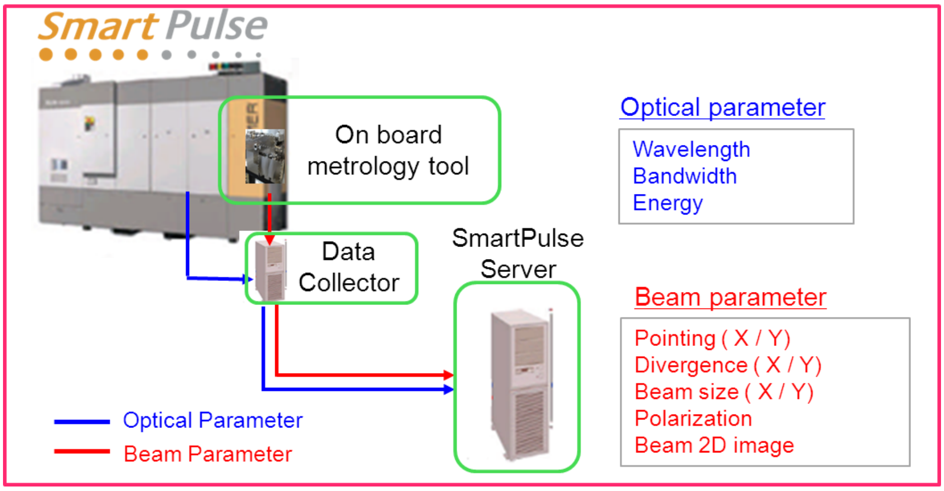


Figure 6. SmartPulse Data Collection Architecture

3.2 CD results and comparison

Figure 7. (a) shows the wafer experimental results for the Trench pattern CD error vs. bandwidth E95for various pitches. Comparing to pervious Trench simulation results, the simulation trend is consistent with the wafer experiment; the pitch-I' is the critical pitch to limit the bandwidth E95, and it needs to be controlled within 415fm (by simulation) or 430fm (by wafer experiment) to ensure the proximity error with 4% of target CD. We can calculate the contribution of laser bandwidth E95 variation to proximity budget from the ΔCD / ΔE95 error sensitivity.

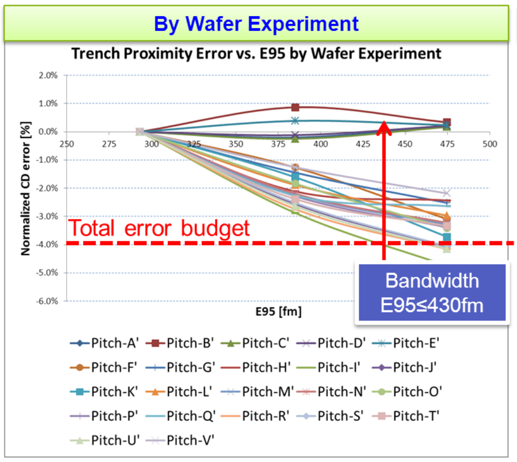


Figure 7. (a) Trench wafer experiment result

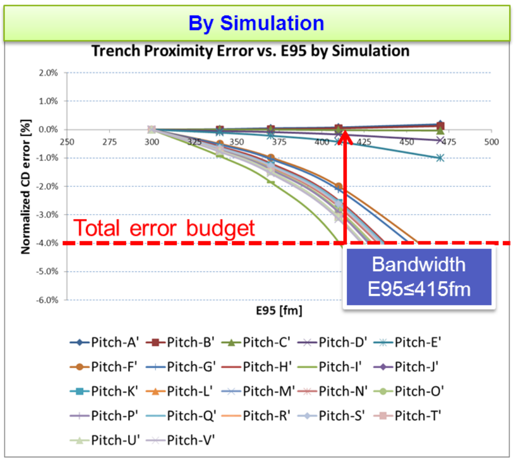
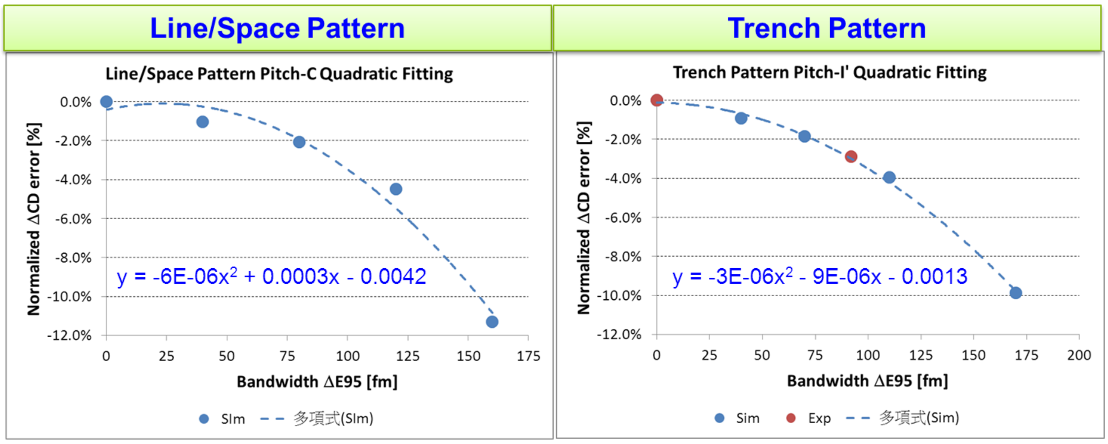


Figure 7. (b) Trench simulation result

3.3 Quadratic fitting for bandwidth E95 sensitivity

Based on the agreement of Trench wafer experiment and simulation result, we take the most sensitive pitches, pitch-C (Line/Space) from simulation result and pitch-I' (Trench) from simulation and experiment result to calculate the bandwidth sensitivity. The bandwidth impact on CD can be described by a polynomial fit of second order, which will enable determining the ΔCD / ΔE95 sensitivity. Therefore we use the following quadratic curve fitting, $\Delta CD = a * \Delta E95^2 + b * \Delta E95 + c$. ……. (eq 1.) to the simulation and experiment data. Figure 8.(b) shows the Trench pitch-I' quadratic fitting result; the wafer experiment and simulation results are matched and follow the quadratic fitting curve very well. For bandwidth E95 variation within 100fm, the quadratic fitting curve should accurately correspond to the

measured proximity error response. Figure 8.(a) also illustrates the Line/Space pitch-C quadratic fitting result, we assume the simulation result can represent of the real case, since wafer exposure data is not reported.



(a) Line/Space pitch-C (b) Trench pitch-I’

Figure 8. The bandwidth CD sensitivities of Line/Space and Trench

4. LASER BANDWIDTH POPULATION FROM INSTALLED SYSTEM

4.1 Characterize the bandwidth variation

In previous discussion, we collected bandwidth E95 variation (standard deviation) and mean across the wafer during wafer-exposure by SmartPulse data collection in order to characterize the short-term and long-term stability performance of installed systems. The total E95 variation can be estimated by adding the E95 intra-wafer variation from field-to-field data (short-term) and wafer-to-wafer (long-term) variation, and then calculating the total E95 variation by RSS (root sum square):

$$E95_{\,3\sigma\,total} = \sqrt{(E95_{\,3\sigma\,F2F})^2 + (\mathrm{E95}_{\,3\sigma\,\mathrm{W2W}})^2} \qquad \text{……..(eq 2.)}$$

Where

$E95_{\,3\sigma\,total}$: Overall bandwidth E95 variation

$E95_{\,3\sigma\,F2F}$: Field to field bandwidth E95 variation (short-term)

$E95_{\,3\sigma\,W2W}$: Wafer to wafer bandwidth E95 variation (long-term)

4.2 Installed laser systems bandwidth population

In order to determine the nominal performance of bandwidth E95 variation across a population of tools, we collected the six XLR 660ix installed systems performance over 1 month production operation by using SmartPulse data collection to determine the performance levels delivered on-wafer. Figure 9. shows trend plots of bandwidth E95 performance for six systems. The blue dots show the intra-wafer bandwidth E95 1sigma calculated from bandwidth E95 data per exposure field; this is referred to as field-to-field bandwidth E95 variation. The green dots are average bandwidth E95 per wafer. Therefore the long-term (1 month) field-to-field and wafer-to-wafer variation can be estimated by calculating the standard deviation field-to-field data and wafer-to-wafer data across the installed systems.

Figure 10. shows the performance of bandwidth E95 across six systems for field-to-field and wafer-to-wafer variation . The Tool-E has the largest field to field bandwidth E95 variation around 30fm, while Tool-B has the largest wafer-to-wafer bandwidth E95 variation around 35fm. Overall Tool-B has the largest overall total bandwidth E95 variation around 40fm.

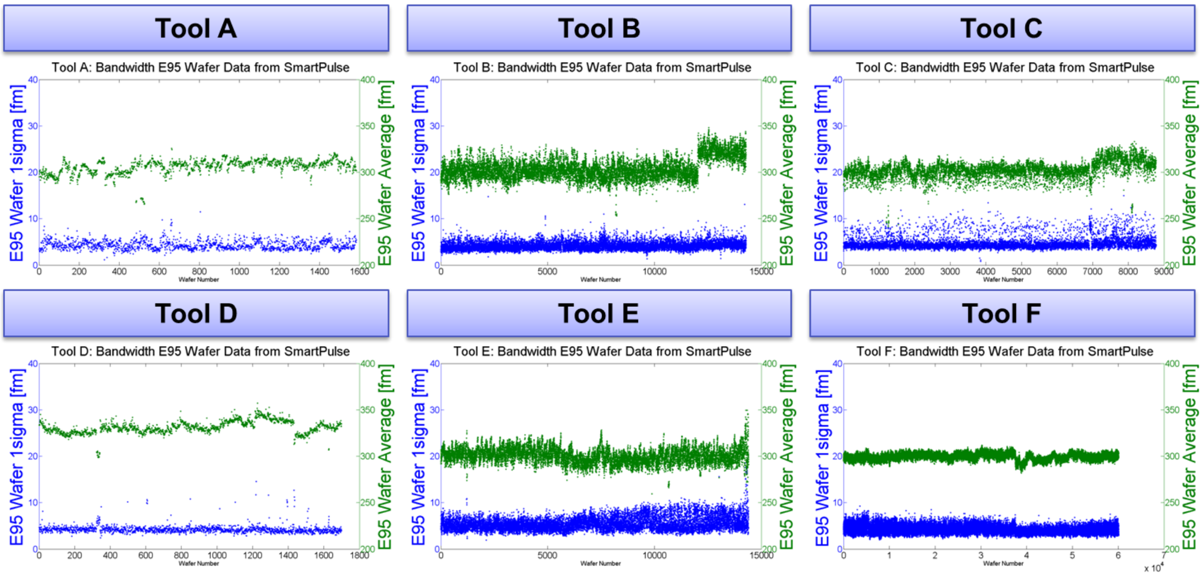


Figure 9. XLR660 ix Installed-system Bandwidth E95 monitoring trends over 1 Month by SmartPulse data collection

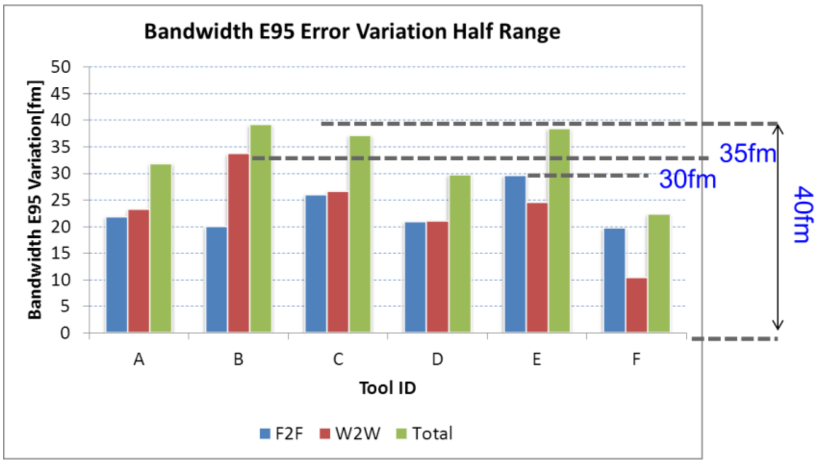


Figure 10. XLR 660ix Installed-system Bandwidth E95 Variation Estimate

4.3 Proximity variation estimated

Taking the critical pitch bandwidth E95 sensitivity from section 3.3and the tool bandwidth E95 variation from section 4.2, the proximity variation due to bandwidth E95 performance can be obtained by (eq 1.). Figure 11. (a) shows the Line/Space feature CD proximity field-to-field (F2F), wafer-to-wafer (W2W) and overall variation; the worst case total variation is around 0.53% of target CD. Figure 11. (b) shows the Trench feature CD proximity field-to-field (F2F), wafer-to-wafer (W2W) and overall variation, with worst case total variation around 0.67% of target CD.

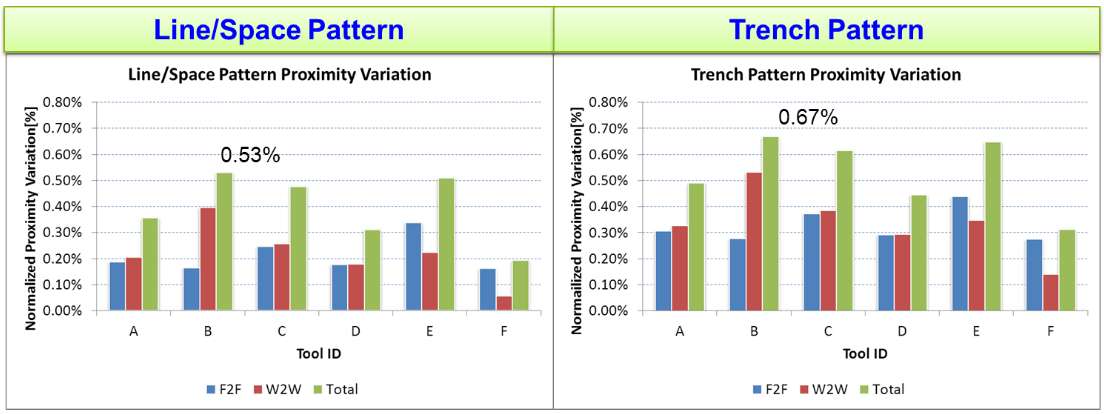


Figure 11. (a) Line/Space proximity variation   Figure 11. (b) Trench proximity variation

4.4 Next advanced design node laser bandwidth stability requirement

As stated previously, for the advanced node design considered in this paper, the proximity contribution by laser bandwidth E95 of current XLR 660ix systems can be 0.67% of target CD. If we assume that the next generation design node requires reducing the CDU budget by half of current node, therefore, in order to keep the same laser bandwidth E95 contribution to proximity CD variation, total (field-to-field and wafer-to-wafer) worst case bandwidth E95 variation of 20fm is required for next generation lasers.

5. CONCLUSION

For the current advanced node design, the total XLR 660ix laser bandwidth E95 variation (field-to-field and wafer-to-wafer), estimated using data from actual wafer exposures using SmartPulse date collection, can contribute ~0.67% of target CD for total bandwidth E95 variation operating at nominal performance. In order to meet the next generation node requirements, assuming half of the total CDU budget of current design node, bandwidth stability within 20fm is required.

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